Strategic Enforcement, Intellectual Property Rights and Contractual R&D

Hamid Beladi, [a *] Sugata Marjit, [b] Xinpeng Xu, [c] Lei Yang [c]

[a] *The University of Texas at San Antonio*
[b] *Centre for Studies in Social Sciences, India*
[c] *The Hong Kong Polytechnic University, Hong Kong*

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Abstract

This paper examines the role of intellectual property rights (IPRs) in developing countries on contractual R&D. We find that strengthened IPRs in developing countries provides incentive for firms, both multinational and local, to specialize in undertaking an R&D activity in which it has competitive advantage (the *specialization effect*). It also facilitates the process for local firms to switch from imitators to potential innovators (the *switching effect*). Moreover, we demonstrate that the multinational firm's strategic behavior on IPRs enforcement can be used as an effective instrument to subsidize contractual R&D in developing countries (the *subsidizing effect*). We further illustrate how a policy mix of IPR and FDI subsidy in developing countries affects R&D activities adding an offshore R&D subsidiary as an additional organizational form.

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[*]Corresponding author: The University of Texas at San Antonio, One UTSA Circle San Antonio, TX 78249, USA. Email: hamid.beladi@utsa.edu; Tel: 210-458-7038; Fax: 210-458-7040.

1. Introduction

In recent decades globalization has led to fragmentation of production across national borders, with each country specializing in a particular stage of the production process. More recently, this pattern of internationalization has extended from production to further up the value-chain – research and development activities, with each country specializing in a particular stage of the research and development (R&D) chain.

How should a developing country reform its IPRs policy to become more conducive to outsourced R&D activities in the era of globalization? We build up a theoretical model to answer this question. We consider a model in which two firms in a developing country, one multinational and one local, produce a product that is composed of two components. The multinational firm and the local firm have competitive advantage in carrying out R&D on component 1 and component 2, respectively. The multinational firm always undertakes R&D on component 1 due to its competitive advantage. The local firm, however, can either engage in R&D on component 2 and license it to the multinational firm as a subcontractor or imitate the multinational firm's technology on component 1 as an imitator without undertaking contractual R&D, depending on the strength of IPRs in the host developing country. In a three-stage game we obtain the following results.

First, we demonstrate that strong IPRs in developing countries may induce firms, both multinational and local, to specialize in one stage of R&D, a "*specialization effect*" attributed to strong IPRs. Second, we consider the possibility that an original imitator in developing countries could eventually become a potential innovator, a "*switching effect*" due to strong IPRs. Third, in contrast to the conventional wisdom, our paper suggests that multinational firm's strategic behavior on IPRs enforcement can be used as an effective

instrument to subsidize contractual R&D in developing countries, which is beneficial to both local firms and multinational firms (the *subsidizing effect*). Fourth, the welfare of developing countries could rise with strong IPRs when contractual R&D can generate substantial cost savings and the bargaining position of the Southern firm is relatively strong. Fifth, we illustrate how a policy mix of IPRs and Foreign Direct Investment (FDI) subsidy in developing countries affects contractual R&D activities by adding an offshore R&D subsidiary as an additional organizational form.

Our interest in contractual R&D is motivated by the recent surge in international fragmentation in research and development. There is considerable evidence of this new trend in a variety of industries. In the pharmaceutical industry, for example, the largest multinationals, including Merck, Eli Lilly, and Johnson & Johnson, are partnering with firms in those countries to carry out sophisticated drug research and clinical testing (Wadhwa 2008a). A Chinese company, Hutchison MediPharma, has formed a similar partnership with Eli Lilly (Wadhwa 2008b). The information technology (IT) industry has also witnessed the rapid expansion of the offshore outsourcing of R&D. Many multinational IT firms, including Dell, Motorola, and Philips, are purchasing not only cell phones but also the complete designs of digital services from Asian developers. In the aerospace industry, Boeing Co. is working with India's HCL Technologies to co-develop software for everything from navigation systems and landing gear to its upcoming 7E7 Dreamliner jet (Engardio and Einhorn 2005).

Data on licensing payments also show a boost in contractual R&D between multinational firms and local firms in developing countries. For example, U.S. licensing payments to Chinese firms rose from $1 million in 1995 to $13 million in 2000, reaching

$115 million in 2007. U.S. licensing payments to Indian firms rose from $2 million in 2000 to $98 million in 2007.[1] China's official balance of payment statistics show that the licensing fee payments received by Chinese firms have registered a substantial increase, rising from US$82 million in 2000 to US$343 million in 2007.

The proliferation of international specialization in R&D activities can be attributed to the following factors. First, several developing countries, for example, India, China, and Brazil, have succeeded in building up their R&D capacity in recent years, thereby reducing the technology gap between themselves and developed countries. Second, R&D in certain industries, for example, the pharmaceutical industry, is highly complex and prohibitively expensive. The intensification of globalization has put multinational firms under pressure to reduce their R&D costs. Such factors as lower labor costs, time savings due to the time difference between some developed and developing countries, higher patient enrolment rates, as well as the prevalence of a wide variety of diseases and heterogeneous gene pool, all contribute to the cost advantage enjoyed by developing nations in the drug research process.[2] Hence the strategy adopted by many multinational firms is to specialize in a particular component of the R&D chain to reduce R&D costs.

Our study builds on the line of literature concerning the role of IPRs in developing countries on innovation and economic growth. There are mixed views on developing countries' IPRs policies. On the one hand, there are concerns that strengthening IPRs may not be in the interests of developing countries, as stronger IPRs lead to an increase in

[1] These data are from the U.S. Department of Commerce, available at http://www.bea.gov/international/intlserv.htm.

[2] For example, bringing a new molecule to the market in the pharmaceutical industry was estimated to cost about $800 million in 2005, out of which a significant portion was spent on testing the drug on patients prior to commercial approval. A recent McKinsey study suggested that the cost saving realized in the drug research process would be about $200 million if clinical trials were carried out in India. See "The HINDU survey of Indian Industry 2004", available at http://www.thehindu.com.

imitation costs of the Southern firms (Chin and Grossman 1990), a reduction in consumer surpluses due to monopoly pricing (Deardorff 1992), and the diminishing of both developed countries' rates of innovation and developing countries' welfare in the long run (Helpman 1993). On the other hand, recent studies suggest that strong IPRs may benefit developing countries, as they encourage the inward flow of technology, close the gap in technological sophistication between these countries and developed countries, and lead to a flowering of local innovation (see Maskus 1995, Maskus 2000, and Chen and Puttitanun 2005, among others).

None of the aforementioned studies, however, has touched upon the impacts of stronger IPRs in developing countries on contractual R&D activities. Our paper fills this gap in the literature by establishing a link between IPRs and international contractual R&D, which offers a new perspective on the protection of IPRs in developing countries.

Our paper is related to the literature on the link between IPRs in developing countries and domestic innovations. Chen and Puttitanun (2005) find that although stronger IPRs encourage domestic innovation, it also make it more difficult for a domestic imitator to imitate a more advanced foreign firm's technology in the import sector. Hence, developing countries need to balance these two effects in deciding on IPRs policies. Mukherjee and Sinha (2013) show that stronger IPRs in the South may make the northern firm worse off and the Southern firm better off by increasing the Southern firms' incentive for innovation. Our paper complements the aforementioned literature by focusing on the following factors. First, we consider the role of IPRs in a context in which both the multinational and local firm have competitive advantage in one stage of the R&D chain. Therefore we focus on the case where the multinational and local firm

innovates on different components instead of the same component. Second, we consider the possibility that an original imitator in a developing country may switch to an innovator. Third, we show the implications of strategic IPRs enforcement.

Our paper is also associated with the strand of literature on IPRs and R&D competition. Chowdhury (2005) argues that patent protection reduces R&D investment if the tournament effect is negative. Mukherjee (2006) shows that the effect of either imitation or technology licensing may dominate the tournament effect and create higher R&D investment under patent protection.

The remainder of the paper is organized as follows. In Section 2 we present a basic model of contractual R&D. We analyze the equilibrium results under no patent protection, under strong patent protection and under strategic IPRs enforcement in Section 3. The impacts of changes in IPRs regime on the Southern welfare are investigated in Section 4. We further examine how results will be changed by adding an R&D subsidiary in Section 5. We offer concluding remarks in the final section.

2. The basic setup

In this section we lay out a model which captures the current feature of the internationalization of R&D activities. Consider a market with two firms, one N firm (the multinational) and one S firm (the local),[4] producing a homogeneous product using two components and compete in Cournot fashion in the South. If a represents the market size of the South, the inverse-demand function for our product is given by $P = a - q$, where P

[4] Our findings remain qualitatively intact with different numbers of Southern firms engaging in quantity competition.

is the price of the product and q the quantity produced.[5] Let c_i ($i = 1,2$) denote firms' marginal production costs related to the first and second component, respectively, before process innovation or imitation.[6] Firms' marginal production costs related to component i can be reduced to $\tilde{c}_i$ by process innovation and to $\alpha\tilde{c}_i$ by imitation. Here α is a parameter representing firms' imitation capacity given by such characteristics of the South as education level and infrastructure, where a lower value of α indicates higher imitation capacity. Since the imitator has no access to tacit knowledge including know-how and information gained from experience, we have $\alpha > 1$. Hence we have $\tilde{c}_i < \alpha\tilde{c}_i < c_i$. Thus, both imitation and innovation reduces firms' marginal cost but the decline is greater in the latter case.

Assume that the N firm has competitive advantage in conducting R&D on component 1 because it owns a higher technological level; the S firm has competitive advantage in conducting R&D on component 2 because it has the advantage of lower labor cost and some other advantages discussed in the introduction section. To focus our analysis on firms' incentives to engage in contractual R&D, we assume that only the N firm conducts process innovation on component 1 before the game starts. We also assume that the N firm produces in the North and the S firm produces in the South.[7] Let R_N and R_S denote the component 2 R&D costs of the N firm and the S firm respectively. Here we assume $R_S < R_N$, thus reflecting the S firm's competitive advantage in carrying

[5] We assume market size a is sufficiently greater than marginal costs to ensure positive production of both firms.

[6] The R&D we consider in this paper is cost-reduction R&D, or process innovation, as most contractual R&D activities in developing countries are targeted at cost reduction instead of quality improvement.

[7] In this paper we have chosen to focus on the effects of change in IPR regime on contractual R&D activities between the North and the South. Therefore, issues including trade of final goods and intermediate goods as well as the offshore outsourcing of production are beyond the scope of this paper.

out R&D on component 2. Therefore, the N firm can either undertake in-house R&D on component 2 or outsource the R&D on component 2 to the S firm. If the offshore outsourcing of R&D occurs, then we assume that the N firm offers a take-it-or-leave-it contract with a lump-sum license fee to the S firm which the S firm accepts if it does not become worse-off by doing so.[9] Consequently, the S firm gets its reservation value and all the surplus accrues to the N firm. We denote the lump-sum license fee by L, which must be paid to acquire the component 2 technology innovated by the S firm.

Here we describe the decision structure of this game. In this game, there are two players: the S firm and the N firm. The time sequence of the game is as follows.

In the first stage, the N firm chooses between undertaking in-house R&D on component 2 and offering an R&D contract to the S firm.

If the N firm chooses to undertakes in-house R&D in stage 1, in stage 2 the S firm chooses among three strategies: (i) imitating the component 1 technology without undertaking R&D on component 2 (denoted by s(i) in the game tree); (ii) forgoing imitating the component 1 technology without undertaking R&D on component 2 (denoted by s(ii) in the game tree); (iii) imitating the component 1 technology while conducting R&D on component 2 (denoted by s(iii) in the game tree).[10] Both firms

[9] Our specification of a lump-sum license fee without per-unit royalties captures the fact that a large portion of technology contracts in developing countries share this feature. For example, Vishwasrao (2007) assembled data on all foreign technology licensing agreements entered into by manufacturing firms, unaffiliated with the licensors, in India between 1989 and 1993. Over the period 1991-1993, there were 968 contracts specifying only lump-sum fees, which accounts for 45 percent of all licensing deals.

[10] By assuming that $R_S < \pi_S(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, c_S)$, strategy (ii) will always dominate a strategy of no imitation and no innovation, a potential fourth strategy. This assumption is made to minimize technical details that are not essential for our results. Our findings remain intact if we relax this assumption.

maximize profits by simultaneously choosing the optimal quantities in a Cournot setting and profits are realized in stage 3. [11]

If the N firm offers an R&D contract in stage 1, in stage 2 the S firm chooses whether to accept the R&D contract given the Southern patent scope. If the contract is accepted in stage 2, then the S firm chooses whether to imitate the N firm's component 1 technology in stage 3 and both firms maximize profits by simultaneously choosing the optimal quantities in stage 4. If the contract is rejected in the stage 2, then in stage 3 the S firm chooses among strategies (i), (ii) and (iii). Both firms maximize profits by simultaneously choosing the optimal quantities and profits are realized in stage 4.

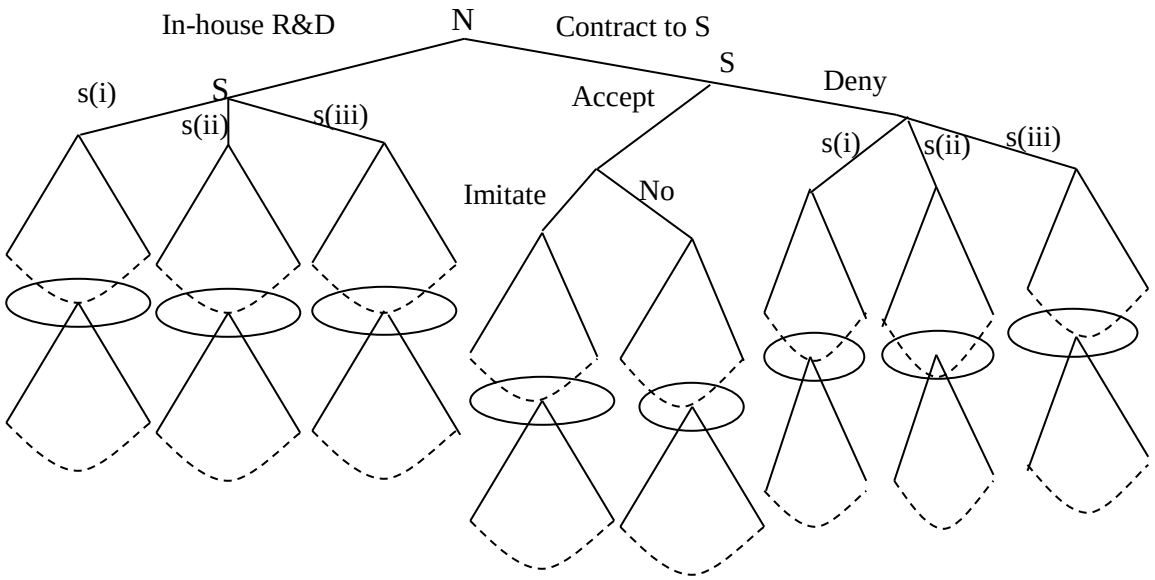

Figure1: The Stages of the Game

[11] We rule out the possibility that the N firm can imitate the S firm's technology on component 2 to avoid the complication of the model. One practical justification for this assumption is the S firm not only applies for a patent for its technology in developing counties, but also in developed countries. Hence, it makes it harder for the N firm to imitate the S firm's technology as the patent protection is much stronger in developed countries.

In the absence of contractual relationship, we assume that imitation of the N firm's component 1 technology can be achieved through product inspection, reverse engineering, or simple trial and error by paying related imitation costs. Stronger IPRs make it harder for S to imitate N's product, either due to broader patent scope that limits reverse engineering or greater enforcement against infringement. Hence we assume that the S firm's imitation cost in the absence of contractual relationship under weak patent protection and that under strong patent protection are I_0 and I_0' respectively, where $I_0 < I_0'$.

In the presence of contractual relationship, the S firm has access to the N firm's component 1 technology as the N firm has to reveal information on component 1 to the S firm to facilitate the latter's innovation on component 2. In this event the N firm will use injunctive remedies to deter the S firm's imitation. The magnitude of injunctive remedies depends on the strength of patent protection of the S country. Thus the S firm's incentive on imitation with contractual relationship also depends on the strength of patent protection of the S country. Let I_1 and I_1' denote the S firm's imitation cost with a contractual relationship in the form of fines from injunctive remedies under weak patent protection and that under strong patent protection respectively and we have $I_1 < I_1'$.

In this context we assume that $f(\ ,\ )$ represents the production relationship between marginal production costs of components and the firms' marginal production costs of the product, where the first (second) argument is the marginal cost of the component 1(component 2).[14] Suppose the N firm's marginal production costs of the product are c_N and $\tilde{c}_N$ in the absence and presence of process R&D on component 2,

[14] The precise form of $f(\ ,\ )$ is not crucial for our results.

respectively. Thus, we have $c_N = f(\tilde{c}_1, c_2)$ and $\tilde{c}_N = f(\tilde{c}_1, \tilde{c}_2)$. Let the S firm's marginal production cost be c_S^α, $\tilde{c}_S$ and $\tilde{c}_S^\alpha$ under strategy (i), (ii) and (iii), respectively. Hence, we have $c_S^\alpha = f(\alpha\tilde{c}_1, c_2)$, $\tilde{c}_S = f(c_1, \tilde{c}_2)$, and $\tilde{c}_S^\alpha = f(\alpha\tilde{c}_1, \tilde{c}_2)$. As $\tilde{c}_i < \alpha\tilde{c}_i < c_i (i = 1,2)$, we have $\tilde{c}_S^\alpha < \tilde{c}_S < c_S^\alpha$. We also denote the profit function of firm j by $\pi_j(\ ,\ )\ (j = N, S)$, where the first (second) argument is the marginal cost of the N firm (the S firm).

We now proceed to discuss the behavior and payoff of firms in two cases: one with weak patent protection and the other with strengthened patent protection.

3. The Impacts of Patent Regime

3.1 Weak Patent Protection

We first consider the case of weak patent protection in the developing country. Patent protection strength of a country refers to the adequacy the laws and regulations it has in place as well as enforcement mechanism in order to provide transparency and certainty for investors, licensees, and customers (Maskus 2004). In our context weak patent protection means that firms pay lower imitation costs both in the absence and presence of contractual relationship if there is an infringement of existing patents.

We solve the subgame perfect equilibrium of the game through the usual method of backward induction. We begin by analyzing the case of successful licensing. In this event, the S firm undertakes R&D on component 2 and licenses it to the N firm in stage 2. With regard to component 1 technology, in principle the S firm could have two choices. The S firm could produce at $\tilde{c}_S$ without pirating the N firm's technology.

Alternatively, it could produce as efficient as the N firm by pirating its component 1 technology as the latter has to reveal information on component 1 to the S firm to facilitate the latter's innovation on component 2. In this event, the S firm's production cost becomes $\tilde{c}_N$. By doing so the S firm has to pay I_1 as the injunctive remedies. Alternatively, the S firm could choose not to imitate under licensing. We assume that $I_1 < \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, \tilde{c}_S)$, thus in equilibrium the S firm chooses to pirate the N firm's component 1 technology and produces at $\tilde{c}_N$. Hence the production profits of the N and the S firm with a successful licensing are given by $\pi_N(\tilde{c}_N, \tilde{c}_N)$ and $\pi_S(\tilde{c}_N, \tilde{c}_N)$, respectively. Accordingly, their payoffs under licensing are given by $\pi_N(\tilde{c}_N, \tilde{c}_N) - L$ and $\pi_N(\tilde{c}_N, \tilde{c}_N) + L - R_S$.

If the N firm's licensing contract is rejected, the N firm undertakes in-house R&D on component 2 and the S firm chooses among three options mentioned in section 2.

Here we summarize the profits of the N firm and the S firm in different scenarios in the following table.

		Profit of the N firm	Profit of the S firm
With contractual R&D		$\pi_N(\tilde{c}_N, \tilde{c}_N) - L$	$\pi_S(\tilde{c}_N, \tilde{c}_N) + L - R_S$
Without contractual R&D	The S firm chooses strategy (i)	$\pi_N(\tilde{c}_N, c_S^\alpha) - R_N$	$\pi_S(\tilde{c}_N, c_S^\alpha) - I_0$
	The S firm chooses strategy (ii)	$\pi_N(\tilde{c}_N, \tilde{c}_S) - R_N$	$\pi_S(\tilde{c}_N, \tilde{c}_S) - R_S$
	The S firm chooses strategy (iii)	$\pi_N(\tilde{c}_N, \tilde{c}_S^\alpha) - R_N$	$\pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - R_S - I_0$

Table 1: Profits in different scenarios under weak patent protection

The above profit functions show that high N firm's R&D cost on component 2 and high S firm's imitation capacity will decrease the profit of the N firm, while high S firm's R&D cost on component 2, high S firm's imitation cost on component 1 and low S firm's imitation capacity will decrease the profit of the S firm.

We assume that the imitation cost under weak patent protection is low so that $I_0 < \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_S(\tilde{c}_N, \tilde{c}_S)$. In this event strategy (ii) is dominated by strategy (iii).

Licensing could only occur if the profit under licensing of each firm is greater than that under an outside option. Here we discuss two cases.

If $R_S < \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_S(\tilde{c}_N, c_S^{\alpha})$, strategy (iii) dominates strategy (i) for the S firm. Thus the reservation values of a successful licensing are payoffs under strategy (iii). As the S firm's production profit under licensing is greater than its payoff under strategy (iii) ($\pi_S(\tilde{c}_N, \tilde{c}_N) - R_S > \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - R_S - I_0$), we have $L = 0$. This result arises due to the fact having access to the N firm's component 1 technology under licensing enhances its production efficiency. We next analyze the N firm's incentive on outsourcing the R&D on component 2 to the S firm. By comparing the N firm's payoff under licensing and that under strategy (iii), we find that a successful licensing occurs when $R_N > \pi_N(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_N)$.

If $R_S > \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_S(\tilde{c}_N, c_S^{\alpha})$, strategy (i) dominates strategy (iii) for the S firm. Under this scenario we have two cases. When $R_S < \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^{\alpha}) + I_0$, the S firm's production profit under contractual R&D is greater than that under strategy (i). Thus we have $L = 0$. By comparing the N firm's payoff under licensing and that under strategy (i), we find that a successful licensing occurs when $R_N > \pi_N(\tilde{c}_N, c_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_N)$.

When $R_S > \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^\alpha) + I_0$, the S firm's production profit under contractual R&D is less than that under strategy (i). Hence we have $L = \pi_S(\tilde{c}_N, c_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_N) + R_S$. Comparing the N firm's payoff under licensing and that under strategy (i), we find that licensing only occurs when $\pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_N) - R_S > \pi_N(\tilde{c}_N, c_S^\alpha) + \pi_N(\tilde{c}_N, c_S^\alpha) - R_N$. Marjit (1990)[15] shows that in a Cournot duopoly model the industry profit increases as one of the firms are more efficient given that these two firms are reasonably close in terms of their initial technologies. Therefore in this case a successful licensing where the reservation values are payoffs under strategy (i) always occurs.

Let a_1 and a_2 denote $\pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, c_S^\alpha)$ and $\pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^\alpha) + I_0$ respectively; let b_1 and b_2 denote $\pi_N(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_N(\tilde{c}_N, \tilde{c}_N)$ and $\pi_N(\tilde{c}_N, c_S^\alpha) - \pi_N(\tilde{c}_N, \tilde{c}_N)$ respectively. We have $a_1 < a_2$ and $b_1 < b_2$. We immediately have the following lemma.

Lemma 1. *(1) A successful licensing occurs where the reservation values are payoffs under strategy (iii) for $R_S < a_1$ and $R_N > b_1$; (2) A successful licensing where the reservation values are the payoffs under strategy (i) occurs for $a_1 < R_S < a_2$ and $R_N > b_2$; (3) Licensing always occurs for $R_S > a_2$.*

The economic intuition is as follows. When R_S is small ($R_S < a_2$), a large R_N reduces the N firm's reservation value, which increases its incentive for licensing. When

[15] Let c_1 and c_2 denote firm 1 and firm 2's marginal production cost and assume $c_1 < c_2$. As is shown in Marjit (1990), the Cournot industry profit decreases with c_2 if $c_2 < \frac{a + 4c_1}{5}$. The economic intuition is that the loss in profit of firm 1 can only be compensated by an increase in profit of firm 2 when the initial market share of firm 2 is sufficiently large (technology gap between firm 1 and firm 2 is close enough).

R_S is large ($R_S > a_2$), the S firm's outside option is strategy (i) (imitating the component 1 technology without undertaking R&D on component 2). By changing from strategy (i) to contractual R&D, the industry profit increases as the S firm becomes more efficient therefore licensing always occurs.

From the conditions for a successful licensing under weak patent protection, we also have the following lemma.

Lemma 2. *Under weak patent protection in the South contractual R&D becomes more likely under low S firm's R&D cost on component 2, high N firm's R&D cost on component 2 and low S firm's imitation capacity.*

3.2 Strong Patent Protection

Now consider the case with strong patent protection, where the Southern country provides adequate laws and regulations as well as enforcement. It implies that firms have to pay higher imitation costs in the absence ($I_0 < I_0'$) and higher injunctive remedies ($I_1 < I_1'$) in the presence of contractual relationship if there is an infringement of existing patents. We first analyze the scenario where the N firm always brings a law suit against the S firm if the S firm imitates the N firm's process innovation on component 1.

Under strong patent protection it acts as a credible threat that the N firm will bring a lawsuit against the S firm if it imitates the N firm' component 1 technology under contractual R&D. For simplicity we assume that $I_1' > \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, \tilde{c}_S)$, thus the S firm's production profit by pirating the N firm's component 1 technology is less than that without pirating. Hence in equilibrium the S firm undertakes contractual R&D on

component 1 without imitating the N firm's component 1 technology. Accordingly, the payoffs of the N and the S firm with a successful licensing are given by $\pi_N(\tilde{c}_N, \tilde{c}_S) - L$ and $\pi_S(\tilde{c}_N, \tilde{c}_S) - R_S + L$, respectively.[16] If the N firm's licensing contract is rejected, the S firm chooses among three options mentioned in section 2.

Here we summarize the profits of the N firm and the S firm in different scenarios in the following table.

		Profit of the N firm	Profit of the S firm
With contractual R&D		$\pi_N(\tilde{c}_N, \tilde{c}_S) - L$	$\pi_S(\tilde{c}_N, \tilde{c}_S) + L - R_S$
Without contractual R&D	The S firm chooses strategy (i)	$\pi_N(\tilde{c}_N, c_S^\alpha) - R_N$	$\pi_S(\tilde{c}_N, c_S^\alpha) - I_0'$
	The S firm chooses strategy (ii)	$\pi_N(\tilde{c}_N, \tilde{c}_S) - R_N$	$\pi_S(\tilde{c}_N, \tilde{c}_S) - R_S$
	The S firm chooses strategy (iii)	$\pi_N(\tilde{c}_N, \tilde{c}_S^\alpha) - R_N$	$\pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - R_S - I_0'$

Table 2: Profits in different scenarios under strong patent protection

We first consider the case that strategy (iii) dominates strategy (ii) for $I_0' < \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_S)$. In this scenario we have two cases.

First, if $R_S < \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, c_S^\alpha)$, strategy (iii) dominates strategy (i) for the S firm. Thus the S firm's reservation value of a successful licensing is his payoff under strategy (iii). Therefore we have $L = \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_S) - I_0'$. By comparing the N firm's payoff

[16] Our results would be essentially the same if we consider the possibility that the S firm commits not to produce after a successful licensing under strengthened IPR. Under such circumstances the N firm is a monopoly in the market and the S firm does not produce in the third stage.

under licensing and that under strategy (i), we find that a successful licensing occurs when $R_N > \pi_N(\tilde{c}_N, \tilde{c}_S^{\alpha}) + \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, \tilde{c}_S) - I_0'$.

Second, if $R_S > \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_S(\tilde{c}_N, c_S^{\alpha})$, strategy (i) dominates strategy (iii) for the S firm. In this event we have two cases. When $R_S < \pi_S(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, c_S^{\alpha}) + I_0'$, the S firm's production profit under contractual R&D is greater than that under strategy (i). Thus we have $L = 0$. Therefore a successful licensing occurs when $R_N > \pi_N(\tilde{c}_N, c_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S)$. When $R_S > \pi_S(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, c_S^{\alpha}) + I_0'$, we have $L = \pi_S(\tilde{c}_N, c_S^{\alpha}) - \pi_S(\tilde{c}_N, \tilde{c}_S) + R_S - I_0'$ and licensing only occurs when $\pi_N(\tilde{c}_N, \tilde{c}_S) + \pi_S(\tilde{c}_N, \tilde{c}_S) + R_N + I_0' > \pi_N(\tilde{c}_N, c_S^{\alpha}) + \pi_S(\tilde{c}_N, c_S^{\alpha}) + R_S$. As this condition always holds, a successful licensing always occurs in this event.

We next consider the case that strategy (ii) dominates strategy (iii) for $I_0' > \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_S(\tilde{c}_N, \tilde{c}_S)$. Under this scenario the S firm's production profit under contractual R&D is the same as his reservation value, therefore $L = 0$ and licensing always occurs.

Let a_2' denote $\pi_S(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, c_S^{\alpha}) + I_0'$; let b_1' and b_2' denote $\pi_N(\tilde{c}_N, \tilde{c}_S^{\alpha}) + \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, \tilde{c}_S) - I_0'$ and $\pi_N(\tilde{c}_N, c_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S)$ respectively. The equilibrium results under strong patent protection can be summarized as follows. (1) A successful licensing occurs where the reservation values are payoffs under strategy (iii) for $R_S < a_1$ and $R_N > b_1'$; (2) A successful licensing where the reservation values are the payoffs under strategy (i) occurs for $a_1 < R_S < a_2'$ and $R_N > b_2'$; (3) A successful licensing always occurs for $R_S > a_2'$.

The difference between b_1' and b_1 is given by $b_1' - b_1 = \pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, \tilde{c}_S) - I_0'$. Hence we have $b_1' < b_1$ when $\pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - \pi_N(\tilde{c}_N, \tilde{c}_S) - \pi_S(\tilde{c}_N, \tilde{c}_S) < I_0'$. We also have $b_2' - b_2 = \pi_N(\tilde{c}_N, \tilde{c}_N) - \pi_N(\tilde{c}_N, \tilde{c}_S) < 0$. Note that a lower b_1' (b_1) and b_2' (b_2) imply that contractual R&D is more likely. Thus we find that contractual R&D would occur under strengthened patent protection, but would not occur under weak patent protection for (1) $R_S < a_1$ and $b_1 < R_N < b_1'$; (2) $a_1 < R_S < a_2$ and $b_2' < R_N < b_2$. Hence, we have the following proposition.

Proposition 1. *Patent protection would increase firms' incentive for specialization in undertaking R&D when each firm has competitive advantage in research and development in one component and the S firm has low imitation capacity.*

The economic intuition is as follows. Under no patent protection, it could be more profitable for firms to imitate their competitor's technology as they do not need to pay an imitation cost in the form of fines from the law suits. Strengthened patent protection thus reduces firms' incentive to imitate as they face the imitation cost and enhances the S firm's incentive to shift from imitation to conducting cooperative R&D. Lower imitation capacity of the S firm also reduces its reservation value and enhances its incentive to change from an imitator to an innovator.

3.3 Strategic Enforcement

In this section we discuss the possibility that the N firm may choose strategic weak IPRs enforcement even though the Southern government provides adequate laws and

regulations, in the sense that the N firm may choose not to bring a law suit against the S firm when the S firm imitates the N firm's technology on component 1.

To include the N firm's strategic incentive on IPRs enforcement, the time sequence of the game is modified as follows. If the N firm conducts in-house R&D or the contract is rejected in stage 2 the game is the same as that described in section 2. If the contract is accepted in stage 2, the N firm chooses between strong enforcement and strategic weak enforcement in the stage 3. Given the choice of the N firm on IPRs enforcement the S firm chooses whether to imitate the N firm's component 1 technology in the stage 4 and both firms compete in quantities in the stage 5.

If the N firm chooses strong enforcement, the S firm does not imitate the N firm's component 1 technology under contractual R&D, knowing the N firm will bring a lawsuit against it with patent infringement. The payoffs of the N and the S firm are given by $\pi_N(\tilde{c}_N, \tilde{c}_S) - L$ and $\pi_S(\tilde{c}_N, \tilde{c}_S) + L - R_S$ respectively. If the N firm chooses strategic weak enforcement, the S firm is permitted to imitate the N firm's component 1 technology under contractual R&D and the payoffs become $\pi_N(\tilde{c}_N, \tilde{c}_N) - L$ and $\pi_S(\tilde{c}_N, \tilde{c}_N) + L - R_S$.

As $\pi_S(\tilde{c}_N, \tilde{c}_N) + L - R_S > \pi_S(\tilde{c}_N, \tilde{c}_S) + L - R_S$ the S firm chooses to imitate the N firm's component 1 technology under strategic IPR enforcement. Note that the industry profit increases as one of the firms are more efficient when these two firms are reasonably close in terms of their initial technologies. As $\tilde{c}_N < \tilde{c}_S$, we find that the industry profit under strategic weak IPR enforcement is greater than that under strong enforcement ($\pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_N) - R_S > \pi_N(\tilde{c}_N, \tilde{c}_S) + \pi_S(\tilde{c}_N, \tilde{c}_S) - R_S$). This result suggests that strategic weak enforcement increases the joint industry profit. As the N firm makes a take-it-or-leave-it contract to the S firm, it extracts all the increase in the industry profit

while the S firm only gets its reservation value. Thus the N firm could be better off under strategic weak IPRs enforcement compared to that under strong enforcement.

In the absence of a successful R&D contract, the profit functions under strategic weak enforcement are the same as those under strong enforcement. The profits of the N firm and the S firm in different scenarios are summarized in the following table.

		Profit of the N firm	Profit of the S firm
With contractual R&D		$\pi_N(\tilde{c}_N,\tilde{c}_N)-L$	$\pi_S(\tilde{c}_N,\tilde{c}_N)+L-R_S$
Without contractual R&D	The S firm chooses strategy (i)	$\pi_N(\tilde{c}_N,c_S^\alpha)-R_N$	$\pi_S(\tilde{c}_N,c_S^\alpha)-I_0'$
	The S firm chooses strategy (ii)	$\pi_N(\tilde{c}_N,\tilde{c}_S)-R_N$	$\pi_S(\tilde{c}_N,\tilde{c}_S)-R_S$
	The S firm chooses strategy (iii)	$\pi_N(\tilde{c}_N,\tilde{c}_S^\alpha)-R_N$	$\pi_S(\tilde{c}_N,\tilde{c}_S^\alpha)-R_S-I_0'$

Table 3: Profits in different scenarios under strategic patent protection

We first consider the case that strategy (iii) dominates strategy (ii) for $I_0' < \pi_S(\tilde{c}_N,\tilde{c}_S^\alpha)-\pi_S(\tilde{c}_N,\tilde{c}_S)$. In this scenario we have two cases.

First, if $R_S < \pi_S(\tilde{c}_N,\tilde{c}_S^\alpha)-\pi_S(\tilde{c}_N,c_S^\alpha)$, strategy (iii) dominates strategy (i) for the S firm. Thus the S firm's reservation value of a successful licensing is his payoff under strategy (iii). In this case we find $L=0$ and a successful licensing always occurs.

Second, if $R_S > \pi_S(\tilde{c}_N,\tilde{c}_S^\alpha)-\pi_S(\tilde{c}_N,c_S^\alpha)$, strategy (i) dominates strategy (iii) for the S firm. In this event we have two cases. When $\pi_S(\tilde{c}_N,\tilde{c}_S^\alpha)-\pi_S(\tilde{c}_N,c_S^\alpha) < R_S < \pi_S(\tilde{c}_N,\tilde{c}_N)-\pi_S(\tilde{c}_N,c_S^\alpha)+I_0'$ we have $L=0$ and a successful

licensing occurs if $R_N > \pi_N(\tilde{c}_N, c_S^\alpha) - \pi_N(\tilde{c}_N, \tilde{c}_N)$. When $R_S > \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^\alpha) + I_0'$, the S firm's production profit under licensing is less than its payoff under strategy (iii). Hence we find $L = \pi_S(\tilde{c}_N, c_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_N) + R_S - I_0'$ and licensing only occurs when $\pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_N) - R_S > \pi_N(\tilde{c}_N, c_S^\alpha) + \pi_S(\tilde{c}_N, c_S^\alpha) - R_N - I_0'$. As this condition always holds, contractual R&D where the reservation values are payoffs under strategy (i) always occurs.

We next consider the case when strategy (ii) dominates strategy (iii) for $I_0' > \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_S)$. In this event $L = 0$ and a successful licensing always occurs.

Let a_3 denote $\pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^\alpha) + I_0'$. The equilibrium results under strategic weak enforcement can be summarized as follows. (1) Contractual R&D always occurs for $R_S < a_1$ where the reservation values are payoffs of strategy (iii); (2) Contractual R&D occurs for $a_1 < R_S < a_3$ and $R_N > b_2$ where the reservation values are payoffs of strategy (i); (3) Contractual R&D always occurs for $R_S > a_3$ where the reservation values are payoffs of strategy (i).

Comparing the equilibrium results with strategic weak enforcement and those with strong enforcement, it can be shown that for contractual R&D would not occur with strong IPRs enforcement but would occur with strategic weak enforcement for $R_N < b_1'$ when $R_S < a_1$. Hence, contractual R&D becomes more likely when allowing for the option of strategic weak IPR enforcement. Therefore the following proposition is immediate.

Proposition 2. *The N firm's Strategic Behavior on weak enforcement of IPR could*

increase the possibility of contractual R&D in developing countries.

The intuition is as follows. When the difference of the R&D cost on component 2 between the N firm and the S firm is small ($R_S < R_N < b_1'$), under strong patent protection the S firm has no incentive to switch from imitation to undertaking contractual R&D because the total benefit under contractual R&D is not big enough to cover the S firm's loss under imitation. When strategic weak IPR enforcement becomes an option, the S firm is able to produce more efficiently by imitating the N firm's component 1 technology under contractual R&D, which in turn increases the total industry profit under contractual R&D. Under such circumstances the total benefit under contractual R&D can cover the S firm's loss from the switch, hence contractual R&D becomes more likely. Thus the increase in the total industry profit changing from strong enforcement to strategic weak enforcement can serve as a subsidy for the S firm to switch from pure imitation to undertaking contractual R&D. This is the subsidizing effect from the strategic weak enforcement of the N firm.

We illustrate the above equilibrium results under different circumstances in Figure 1, Figure 2 and Figure 3 where the horizontal axis and the vertical axis represent the R&D cost on component 2 of the S firm and the N firm respectively. Shaded area in region I, II and III in Figure 1 represent the equilibrium when contractual R&D occurs under weak patent protection. Note that the N firm's R&D cost on component 2 is greater than the R&D cost of the S firm. Under strong patent protection the equilibrium when contractual R&D occurs corresponds to Shaded area in Region I and II in Figure 2. In the

event of strategic weak IPR enforcement, the equilibrium when contractual R&D occurs corresponds to Shaded area in region I, II and III in Figure 3.

3.4 A Note on Cross Licensing

In principle, the N firm could also license the component 1 technology to the S firm. Although licensing of component 1 technology from the N firm to the S firm is often not feasible in the real world because the N firm tends to protect its core technologies from leakage, we discuss how our results will be changed if we include this possibility. [17]

Cross licensing occurs when the S firm licenses component 2 technology to the N firm while the N firm licenses component 1 technology to the S firm. From Appendix A we show that cross licensing only occurs under strong patent protection. By comparing the equilibrium results under different scenarios we find that when the S country changes from weak to strong patent protection the incentive for undertaking contractual R&D under cross licensing will be further increased and our conclusions will be strengthened. Under cross licensing given the Southern country provides adequate laws and regulations the N firm has no incentive to undertake strategic weak enforcement because it can only lead to the reduction of the S firm's production efficiency and the total industry surplus which all accrues to the N firm.

4. Welfare impacts of IPRs policy

It is of interest to evaluate the impacts of changes in the patent regime on the Southern welfare, defined as the sum of local consumer surplus and the S firm's profit. The

[17] The mathematical appendix A demonstrates these results..

detailed calculations in this context are complex and, to save space, we simply overview the results here (See Appendix B for mathematical derivations).

4.1 Welfare Impacts of Strengthened IPRs

For the welfare impact, we focus on the analysis where the equilibrium results are changed from a policy change of patent protection regime. We first discuss the change in Southern welfare from weak patent protection to strong patent protection. It is shown that in this event the consumer surplus in the Southern country is increased while the S firm's profit is decreased. The economic intuitions are as follows. First, this policy shift encourages contractual R&D, which increases the productivity of the S firm and expands consumption in the Southern market. Second, the increase in imitation cost decreases the S firm's profit under imitation, thereby decreasing its reservation value under contractual R&D. Accordingly, strengthened IPR decreases the S firm's profit under contractual R&D. The consumer gain due to the increase in the S firm's productivity becomes larger with the increase in the cost saving shifting from imitation to innovation. Further, as the S firm's bargaining strength increases, the S firm's profit as well as the Southern welfare will be enhanced with the strengthened IPR. In brief, strong patent protection will raise local welfare with large cost saving from innovation and the relatively strong bargaining position of the Southern firm. It could decrease the Southern welfare otherwise.

4.2 Welfare Impacts of Strategic Enforcement

For $R_S < a_1$ and $R_N < b_1'$, the equilibrium regime is strategy (iii) under strong enforcement and contractual R&D under strategic weak enforcement. As shown in Appendix B, upon

reaching the licensing equilibrium range, both southern consumer surplus and the S firm's profit are increased. After this policy change, the Southern consumer surplus is increased due to the increase in the S firm's productivity. Also it allows the S firm to imitate without incurring the imitation cost under contractual R&D, thereby increasing the S firm's profit. Accordingly, the Southern welfare rises with the N firm's strategic weak IPRs enforcement.

5. Adding Offshore R&D Subsidiary

We have analyzed the multinational firm's choice between undertaking in-house R&D and outsourcing R&D to a local firm. An alternative organizational choice for a multinational firm is to establish a wholly-owned R&D subsidiary in developing countries. By setting up R&D subsidiaries in developing countries, multinational firms are able to take advantage of lower R&D cost in developing countries. To capture this feature, we now incorporate a simple specification of an R&D subsidiary into the model.

Suppose the N firm has the option of establishing an R&D subsidiary in the South. Following Antràs and Helpman (2004), we assume that the fixed organizational cost under integration abroad (set up an R&D subsidiary) is greater than that under outsourcing (conducting contractual R&D). To simplify the analysis, we assume that a set up cost g is incurred under integration (set up an R&D subsidiary) while no setting up cost is incurred under outsourcing. We also assume that the R&D cost on component 2 of the S subsidiary is R_S, the same as that of the S firm undertaking contractual R&D, reflecting the fact that the S subsidiary can also take advantage of lower R&D cost in

developing countries. As a result, the cost difference between conducting R&D through an R&D subsidiary and through outsourcing is the setting up cost g .

In this setup, the N firm has two outside options: conducting in-house R&D in the North and setting up an R&D subsidiary in the South, while the S firm has three outside options set out in previous sections. Working through the payoff functions we have the following results.[20] If the subsidiary setup costs are large and patent protection is weak, in equilibrium the N firm conducts in-house R&D. In this event the N firm does not choose an R&D subsidiary due to the large set up costs. As the South strengthens its patent protection, the equilibrium shifts from integration at home (conducting in-house R&D in the North) to outsourcing (undertaking contractual R&D). If subsidiary set up cost is sufficiently small while patent protection is weak, in equilibrium the N firm chooses to conduct R&D via an R&D subsidiary. Strengthened patent protection shifts the equilibrium from integration abroad (setting up an R&D subsidiary) to outsourcing (undertaking contractual R&D) in this event. The economic intuition for this result is as follows. When the setting up cost of a R&D subsidiary is sufficiently small, the N firm's reservation value under R&D subsidiary is large. Therefore the N firm may choose to set up a R&D subsidiary instead of contractual R&D under weak patent protection. Under strengthened patent protection, the S firm has no incentive to imitate the N firm's component 1 technology believing that the N firm will bring a lawsuit against the S firm if imitation exists under contractual R&D, hence the N firm's profit under contractual R&D is increased, which makes contractual R&D more likely.

[20] See Appendix C for proof.

In essence the above results can be characterized as follows. In developing countries where subsidiary set up costs are large and patent protection is weak, the N firm chooses to conduct in-house R&D in the North. Strengthened patent protection encourages contractual R&D. Alternatively, the Southern country with weak patent protection may attract an R&D subsidiary by reducing the set up cost of the R&D subsidiary. In particular, the Southern government could focus on the improvement of infrastructure, the institutions as well as providing FDI subsidies including job-creation subsidies, tax cut and even the construction of industrial facilities. Strengthened patent protection could further encourage contractual R&D.

6. Concluding Remarks

This paper offers a new perspective on the protection of IPRs in developing countries. Our analysis yields several interesting results. First, by reducing the Southern firm's profits under imitation, strengthened IPRs in developing countries increases the Southern firm's incentive to undertake contractual R&D, thereby encouraging the international specialization in R&D. Second, the multinational firm's strategic IPRs enforcement may encourage contractual R&D. Further, we find that Southern welfare could rise with strengthened IPRs under large cost saving from innovation and the relatively strong bargaining position of the Southern firm. Finally, we show how a policy mix of IPR and FDI subsidy in developing countries affects R&D activities by adding an offshore R&D subsidiary as an alternative organizational form.

Our analysis can be extended to more general environments. We have assumed that the S firm can only license its technology on one component of a product to one N firm.

However, in the real world it is possible that the S firm may license its technology to multiple N firms who produce differentiated goods but all use the S firm's technology as one component. If we include this possibility, the S firm's bargaining power will be increased because there are a large number of potential buyers. Hence, the S firm has more incentive to undertake contractual R&D and our conclusions will be strengthened.

Another promising avenue for future research is to examine the impact of a policy mix of R&D subsidy and IPR on contractual R&D. Strengthened IPRs policy may change domestic firms' incentive to undertake contractual R&D, which in turn can affect R&D subsidy policy. This analysis will be important for developing countries as R&D subsidy policy plays a vital role in shaping domestic innovative capacities.

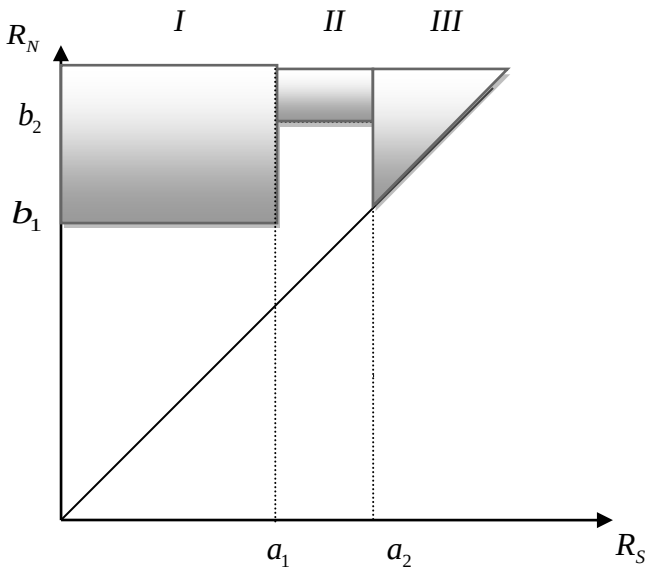

Figure 1. Equilibrium Results under Weak Patent Protection

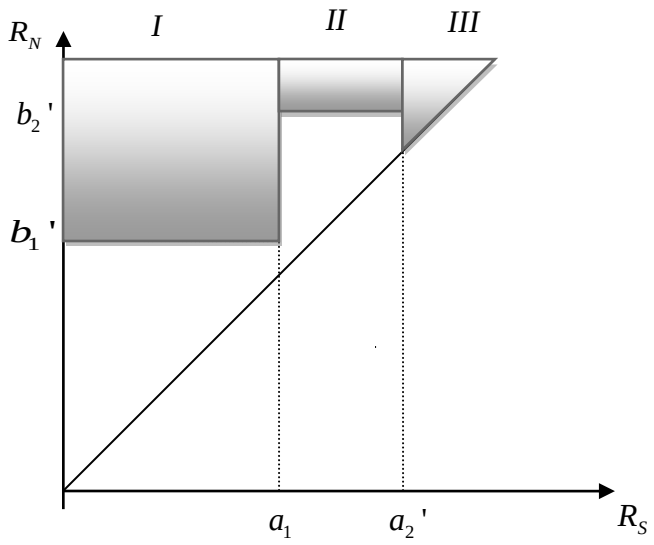

Figure 2. Equilibrium Results under Strong Patent Protection

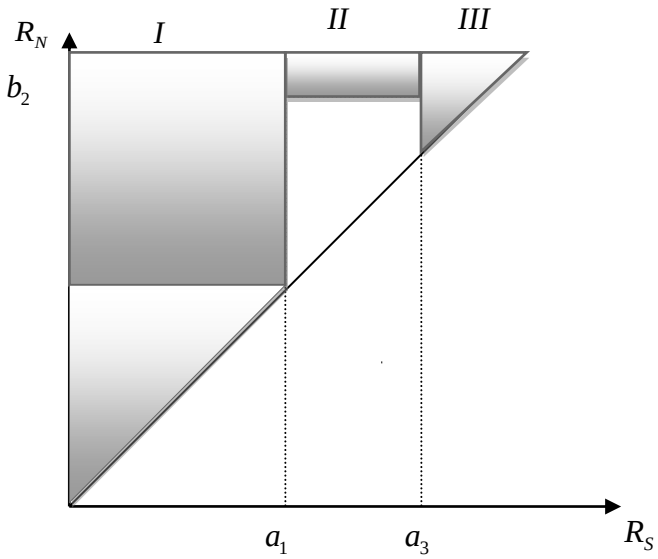

Figure 3. Equilibrium Results under Strategic Weak Enforcement

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Appendix A: The Results with Cross Licensing

Cross licensing occurs when the S firm licenses component 2 technology to the N firm while the N firm licenses component 1 technology to the S firm. Let L_1 and L_2 denote the licensing fee of component 1 technology and component 2 technology respectively under cross licensing. [21] Hence the profit of the N firm and the S firm under cross licensing is given by $\pi_N(\tilde{c}_N,\tilde{c}_N)-L_2+L_1$ and $\pi_S(\tilde{c}_N,\tilde{c}_N)+L_2-L_1-R_S$ respectively. Their profits without contractual R&D are the same as those in table 1.

Under weak patent protection, the S firm produces at $\tilde{c}_N$ by choosing imitation under single licensing. Thus it has no incentive to pay licensing fee to the N firm to get component 1 technology. Hence we have $L_1=0$ and the profits of both firms with the option of the cross licensing are the same as those under single licensing.

Next we demonstrate the equilibrium results under strong patent protection. We first consider the case that strategy (iii) dominates strategy (ii) for $I_0'<\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_S(\tilde{c}_N,\tilde{c}_S)$. In this scenario we have two cases. First, if $R_S<\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_S(\tilde{c}_N,c_S^{\alpha})$, strategy (iii) dominates strategy (i) for the S firm. Thus the S firm's reservation value of a successful licensing is his payoff under strategy (iii). Therefore we have $L_2-L_1=\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_S(\tilde{c}_N,\tilde{c}_N)-I_0'$. Thus we find that a successful licensing occurs when $R_N>\pi_N(\tilde{c}_N,\tilde{c}_S^{\alpha})+\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_N(\tilde{c}_N,\tilde{c}_N)-\pi_S(\tilde{c}_N,\tilde{c}_N)-I_0'$. As $\pi_N(\tilde{c}_N,\tilde{c}_S^{\alpha})+\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_N(\tilde{c}_N,\tilde{c}_N)-\pi_S(\tilde{c}_N,\tilde{c}_N)-I_0'<0$, licensing always occurs in this case. For if $R_S>\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-\pi_S(\tilde{c}_N,c_S^{\alpha})$ there are two possibilities. When $R_S<\pi_S(\tilde{c}_N,\tilde{c}_N)-\pi_S(\tilde{c}_N,c_S^{\alpha})+I_0'$ we have $L_2-L_1=0$ and a successful

[21] To simplify the analysis we assume that cross licensing only occurs under contractual R&D.

licensing occurs if $R_N > \pi_N(\tilde{c}_N, c_S^\alpha) - \pi_N(\tilde{c}_N, \tilde{c}_N)$. When $R_S > \pi_S(\tilde{c}_N, \tilde{c}_N) - \pi_S(\tilde{c}_N, c_S^\alpha) + I_0'$, the S firm's production profit under licensing is less than its payoff under strategy (iii). Hence $L_2 - L_1 = \pi_S(\tilde{c}_N, c_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_N) + R_S - I_0'$ and licensing only occurs. Second, if $R_S > \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, c_S^\alpha)$, strategy (i) dominates strategy (iii) for the S firm. Hence we have $L_2 - L_1 = \pi_S(\tilde{c}_N, c_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_N) + R_S - I_0'$ and licensing occurs when $\pi_N(\tilde{c}_N, \tilde{c}_N) + \pi_S(\tilde{c}_N, \tilde{c}_N) + R_N + I_0' > \pi_N(\tilde{c}_N, c_S^\alpha) + \pi_S(\tilde{c}_N, c_S^\alpha) + R_S$. As this condition always holds, a successful licensing always occurs in this event. We next consider the case that strategy (ii) dominates strategy (iii) for $I_0' > \pi_S(\tilde{c}_N, \tilde{c}_S^\alpha) - \pi_S(\tilde{c}_N, \tilde{c}_S)$. Under this scenario the S firm's production profit under contractual R&D is the same as his reservation value, therefore $L_2 - L_1 = 0$ and licensing always occurs.

The equilibrium results with cross licensing under strong patent protection can be summarized as follows. (1) A successful licensing always occurs where the reservation values are payoffs under strategy (iii) for $R_S < a_1$; (2) Contractual R&D occurs for $a_1 < R_S < a_3$ and $R_N > b_2$ where the reservation values are payoffs of strategy (i); (3) Contractual R&D always occurs for $R_S > a_3$ where the reservation values are payoffs of strategy (i). This shows that when the S country changes from weak to strong patent protection with the option of cross licensing the incentive for undertaking contractual R&D will be further increased and our conclusions will be strengthened.

With cross licensing, the S firm will not imitate the N firm's component 1 technology under contractual R&D as it has got the technology through cross licensing. Therefore strategic weak enforcement only occurs under single licensing. Comparing the

equilibrium results with cross licensing under strong patent protection and those under single licensing under strategic enforcement, we find that the N firm has no incentive to undertake strategic weak enforcement because the profits of both firms under contractual R&D are the same in both events.

Appendix B: Southern Welfare

To illustrate the impact of patent protection on southern welfare, we assume the inverse-demand function for our product in the South is given by $P = a - q$, where a represents the market size of the South, the P is the price of the product and q the quantity produced. Welfare of the Southern country is the sum of Southern consumer surplus and the S firm's profit. Let q_N and q_S denote output of the N and S firm in the Southern country. Let CS and W_S represent the Southern consumer surplus and the Southern welfare respectively. Then we have $CS = \frac{(q_S + q_N)^2}{2}$ [22] and $W_S = CS + \pi_S = \frac{(q_S + q_N)^2}{2} + \pi_S$. [23]

[22] Suppose assume the inverse-demand function is $p = a - q$. Let c_1 and c_2 denote firm 1 and firm 2's marginal production cost. Let q_1 and q_2 denote firm 1 and firm 2's equilibrium output in a Cournot competition. The market equilibrium price is given by $p^* = a - (q_1 + q_2)$. Consumer surplus is given by $\int_0^{q_1+q_2} (p - p^*)dq = \int_0^{q_1+q_2} [(a-q) - (a - q_1 - q_2)]dq = \int_0^{q_1+q_2} (q_1 + q_2 - q)dq = \frac{(q_1 + q_2)^2}{2}$.

[23] Given the general assumptions in Cournot competition in footnote 19, the equilibrium outputs of firm 1 and firm 2 are given by $q_1 = \frac{a + c_2 - 2c_1}{3}$ and $q_2 = \frac{a + c_1 - 2c_2}{3}$. Let π_1 and π_2 denote firm 1 and firm 2's equilibrium production profit. Then we have $\pi_1 = (a - q_1 - q_2)q_1 - c_1 q_1 = {q_1}^2$. Similarly $\pi_2 = {q_2}^2$.

B.1 Change in Southern Welfare Shifting from Weak Patent Protection to Strengthened Patent Protection

As discussed in section 3.2, contractual R&D would occur under strengthened patent protection, but would not occur under weak patent protection for (1) $R_S < a_1$ and $b_1 < R_N < b_1'$; (2) $a_1 < R_S < a_2$ and $b_2' < R_N < b_2$. Here we discuss these two cases separately.

For $R_S < a_1$ and $b_1 < R_N < b_1'$, strategy (iii) is the equilibrium under weak patent protection. Hence the marginal production cost of the N firm and the S firm is $\tilde{c}_N$ and $\tilde{c}_S^{\alpha}$ respectively. Therefore we have $q_N = \frac{a + \tilde{c}_S^{\alpha} - 2\tilde{c}_N}{3}$ and $q_S = \frac{a + \tilde{c}_N - 2\tilde{c}_S^{\alpha}}{3}$. We also get $CS = \frac{(q_S + q_N)^2}{2} = \frac{(2a - \tilde{c}_N - \tilde{c}_S^{\alpha})^2}{18}$ and $\pi_S = {q_S}^2 = \frac{(a + \tilde{c}_N - 2\tilde{c}_S^{\alpha})^2}{9} - R_S - I_0$. Thus the southern welfare is given by $\frac{(2a - \tilde{c}_N - \tilde{c}_S^{\alpha})^2}{18} + \frac{(a + \tilde{c}_N - 2\tilde{c}_S^{\alpha})^2}{9} - R_S - I_0$. Under strengthened patent protection, contractual R&D would occur, hence we have $q_N = \frac{a + \tilde{c}_S - 2\tilde{c}_N}{3}$, $q_S = \frac{a + \tilde{c}_N - 2\tilde{c}_S}{3}$, $CS = \frac{(2a - \tilde{c}_N - \tilde{c}_S)^2}{18}$ and $\pi_S = \frac{(a + \tilde{c}_N - 2\tilde{c}_S)^2}{9} - R_S$. Therefore the southern welfare is given by $\frac{(2a - \tilde{c}_N - \tilde{c}_S)^2}{18} + \frac{(a + \tilde{c}_N - 2\tilde{c}_S)^2}{9} - R_S$. As the N firm makes a take-it-or-leave-it contract to the S firm, the S firm's profit under licensing is equivalent to his profit under strategy (iii). Hence the southern welfare can also be written as $\frac{(2a - \tilde{c}_N - \tilde{c}_S)^2}{18} + \frac{(a + \tilde{c}_N - 2\tilde{c}_S^{\alpha})^2}{9} - R_S - I_0'$. Therefore we find that the consumer surplus in the Southern market is increased while the S firm's profit is

decreased with a policy change from weak patent protection to strengthened patent protection.

For $a_1 < R_S < a_2$ and $R_N < b_2$, strategy (i) is the equilibrium under weak patent protection. Hence we have $q_N = \frac{a + c_S^{\alpha} - 2\tilde{c}_N}{3}$ and $q_S = \frac{a + \tilde{c}_N - 2c_S^{\alpha}}{3}$. The southern welfare is given by $\frac{(2a - \tilde{c}_N - c_S^{\alpha})^2}{18} + \frac{(a + \tilde{c}_N - 2c_S^{\alpha})^2}{9} - I_0$. Under strengthened patent protection, the southern welfare becomes $\frac{(2a - \tilde{c}_N - \tilde{c}_S)^2}{18} + \frac{(a + \tilde{c}_N - 2\tilde{c}_S)^2}{9} - R_S$ with a successful licensing. As the S firm's profit under licensing is equivalent to his profit under strategy (i), the southern welfare can also be written as $\frac{(2a - \tilde{c}_N - c_S^{\alpha})^2}{18} + \frac{(a + \tilde{c}_N - 2c_S^{\alpha})^2}{9} - I_0'$. Similarly, we find that the consumer surplus in the Southern country is increased while the S firm's profit is decreased with a policy change from weak patent protection to strengthened patent protection.

B.2 Change in Southern Welfare Shifting from Strong Enforcement to Strategic Weak Enforcement

In this section we focus on the case where a policy change from strong enforcement to strategic weak enforcement changes the equilibrium from no contractual R&D to contractual R&D.

As discussed in section 5, for $R_S < a_1$ and $R_N < b_1'$ strategy (iii) is the equilibrium under weak patent protection. Hence the southern welfare is given by $\frac{(2a - \tilde{c}_N - \tilde{c}_S^{\alpha})^2}{18} + \frac{(a + \tilde{c}_N - 2\tilde{c}_S^{\alpha})^2}{9} - R_S - I_0'$. Under strengthened patent protection the

equilibrium is changed to contractual R&D. Thus the southern welfare is changed to $\frac{(2a-2\tilde{c}_N)^2}{18}+\frac{(a-\tilde{c}_N)^2}{9}-R_S$. Under this scenario both consumer surplus in the southern country and S firm's profit are increased with a policy change from strong enforcement to strategic weak enforcement.

Appendix C: Equilibrium Results with a R&D Subsidiary

First consider the case that the setting up cost of a R&D subsidiary is sufficiently large ($g > R_N - R_S$). In this event the N firm's profit of conducting in-house R&D in the North is greater than that via a R&D subsidiary. As a result the equilibrium results are the same as those discussed above. Under weak patent protection the N firm conducts in-house R&D. As the Southern countries strengthened patent protection, the equilibrium could shift from integration at home (conducting in-house R&D in the North) to outsourcing (undertaking contractual R&D).

Next consider the case that the setting up cost of a R&D subsidiary is sufficiently small ($g < R_N - R_S$). In this case the N firm's profit of conducting in-house R&D in the North is less than that via a R&D subsidiary. In this event the N firm's outside option is setting up an R&D subsidiary in the South, while the S firm has three outside options set out in previous sections in case of a breakup of the negotiation of contractual R&D.

We first discuss the scenario under weak patent protection. The profits of the N firm and the S firm in different scenarios are summarized in the following table. If $R_S < a_1$, strategy (iii) dominates strategy (i) for the S firm. Hence we have $L = 0$ and licensing only occurs when $g > -R_S + b_1$. If $a_1 < R_S < a_2$, strategy (i) dominates strategy (iii) for the S

firm. As the S firm's production profit under contractual R&D is greater than that under strategy (i), we find that $L=0$ and a successful licensing occurs when $g>-R_S+b_2$. If $R_S>a_2$, strategy (i) dominates strategy (iii). We find that the S firm's production profit under contractual R&D is less than that under strategy (i) and licensing always occurs.

		Profit of the N firm	Profit of the S firm
With contractual R&D		$\pi_N(\tilde{c}_N,\tilde{c}_N)-L$	$\pi_S(\tilde{c}_N,\tilde{c}_N)+L-R_S$
Without contractual R&D	The S firm chooses strategy (i)	$\pi_N(\tilde{c}_N,c_S^{\alpha})-R_S-g$	$\pi_S(\tilde{c}_N,c_S^{\alpha})-I_0$
	The S firm chooses strategy (ii)	$\pi_N(\tilde{c}_N,\tilde{c}_S)-R_S-g$	$\pi_S(\tilde{c}_N,\tilde{c}_S)-R_S$
	The S firm chooses strategy (iii)	$\pi_N(\tilde{c}_N,\tilde{c}_S^{\alpha})-R_S-g$	$\pi_S(\tilde{c}_N,\tilde{c}_S^{\alpha})-R_S-I_0$

Table 1: Profits with a R&D Subsidiary in different scenarios under weak patent protection

Under strengthened patent protection, the profits of the N firm and the S firm are summarized in table 4. We have the following findings. If $R_S<a_1$, strategy (iii) dominates strategy (i) for the S firm and licensing only occurs when $g>-R_S+b_1'$. If $R_S>a_1$, strategy (i) dominates strategy (iii) for the S firm and licensing always occurs.

		Profit of the N firm	Profit of the S firm
With contractual R&D		$\pi_N(\tilde{c}_N, \tilde{c}_S) - L$	$\pi_S(\tilde{c}_N, \tilde{c}_S) + L - R_S$
Without contractual R&D	The S firm chooses strategy (i)	$\pi_N(\tilde{c}_N, c_S^{\alpha}) - R_S - g$	$\pi_S(\tilde{c}_N, c_S^{\alpha}) - I_0'$
	The S firm chooses strategy (ii)	$\pi_N(\tilde{c}_N, \tilde{c}_S) - R_S - g$	$\pi_S(\tilde{c}_N, \tilde{c}_S) - R_S$
	The S firm chooses strategy (iii)	$\pi_N(\tilde{c}_N, \tilde{c}_S^{\alpha}) - R_S - g$	$\pi_S(\tilde{c}_N, \tilde{c}_S^{\alpha}) - R_S - I_0'$

Table 2: Profits with a R&D Subsidiary in different scenarios under strong patent protection

Thus, the N firm chooses to conduct R&D via an R&D subsidiary under weak patent protection but switches to contractual R&D under strong patent protection for (1) $R_S < a_1$ and $-R_S + b_1' < g < -R_S + b_1$; (2) $a_1 < R_S < a_2$ and $g < -R_S + b_2$. In this circumstances strengthened patent protection shifts the equilibrium from integration abroad (set up an R&D subsidiary) to outsourcing (undertake contractual R&D).